The Reef at the End of the World

Joshua Sokol

B.A. Astronomy and B.A. English Literature
Swarthmore College, 2011

SUBMITTED TO THE PROGRAM IN COMPARATIVE MEDIA STUDIES/WRITING IN PARTIAL FUFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN SCIENCE WRITING

AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

September 2015

Signature of Author: Signature redacted
Program in Comparative Media Studies/Writing
June 4, 2015

Certified by: Signature redacted
Marcia Bartusiak
Professor of the Practice
Thesis Supervisor

Accepted by: Signature redacted
Thomas Levenson
Professor of Science Writing
Director, Graduate Program in Science Writing

The Reef at the End of the World

Joshua Sokol

Submitted to the Program in Comparative Media Studies/Writing on June 4, 2015 in Partial Fulfillment of the Requirements for the Degree of Master of Science in Science Writing

ABSTRACT

Flippers first, I splash into the year 2100. Graduate student Hannah Barkley and I are swimming in Nikko Bay, among the Rock Islands of Palau. Here the warm blue-green water resembles naturally what the tropical Pacific will be like by the end of the century, as carbon emissions take an ever-greater toll on the seas. It should be a window into a dire, climate-change future. But things here look fine.

In Palau's Nikko Bay and a few other acidified Rock Island sites, life appears to be shrugging off a sneak preview of the coral-reef apocalypse. Now Barkley, her boss Cohen, and the rest of the team are trying to answer a few pressing questions. Are the corals *really* okay? And if so, how? Moreover, what does that mean?

Thesis Supervisor: Marcia Bartusiak
Title: Professor of the Practice of the Graduate Program in Science Writing

Welcome to Tomorrow

Flippers first, I splash into the year 2100. Graduate student Hannah Barkley and I are swimming in Nikko Bay, among the Rock Islands of Palau. Here the warm blue-green water resembles naturally what the tropical Pacific will be like by the end of the century, as carbon emissions take an ever-greater toll on the seas. It should be a window into a dire, climate-change future.

But things here look fine.

Better than fine. It's an explosion in a paint factory. Tumorous yellow mounds and swaths of gnarled, rust-colored fingers like ginger roots cover the sloping ground beneath us. Some aged coral clumps are tipped to the side like fallen trees, their bone-white bases exposed, but new shoots are growing up toward the Sun, at right angles to the old.

Corals extend down the slope toward a flat, sandy bottom. Diving down, Barkley snips a plastic band tying a metal cylinder about the size of a film canister to a patch of coral. It's a temperature logger, she explains, left behind on an earlier trip. By now it's covered in crusty algae and baby corals. I hold on to it while she looks for another.

Fourteen hours ahead of the U.S. East Coast, Palau rises from the Pacific. The Rock Islands, limestone mushrooms made from ancient coral reefs, jut from the water like the terrain around a Bond villain's lair. A World War II battle was fought here and a season of *Survivor* was shot here. Everything is postcard perfect; the sashimi always fresh. Home to only 20,000, Palau is a paradise for life under the sea and a paragon of marine conservation.

It's Barkley's sixth time in Palau, and the seventh research trip to the Micronesian country for Anne Cohen's lab at the Woods Hole Oceanographic Institute in Massachusetts, where Barkley is a Ph.D. student. What began in 2011 as a project to map the water chemistry of the Palauan island system, as a fact-gathering mission in preparation for climate change, has blossomed into something bigger, more prognostic—and more controversial.

Globally, the oceans are changing. Everyone agrees. This is on top of overfishing, runoff, and pollution. The oceans are getting warmer, and heat waves are lasting longer. This is bad news for the many marine organisms that make their living in partnerships with temperature-sensitive algae that feed on sunlight. Like corals.

Adding to that, about a third of the carbon dioxide pumped into the atmosphere by human civilization ends up mixing into the seas, fundamentally altering the ocean's chemistry. Again, everyone agrees. The public name for this—the one that makes scientists butt in to add qualifiers—is ocean acidification. It means that the seas are becoming less hospitable places to the many, many sea creatures that support their squishy bodies by growing hard shells made from calcium carbonate. Again, among the menaced: corals and coral reefs.

Barkley and other researchers under WHOI's Cohen are here in Palau to study how ocean acidification can affect a real reef system. In the flesh, Palau's corals seem worth saving for purely aesthetic reasons. In Nikko Bay alone, there are ledges of rust-colored sheets, red-orange pancake stacks topped with stalactites, dainty brambles of bonsai, and lobes alternatively bright crimson or a mossy green. It's stunning. Attendant tropical fish are everywhere.

But many of the same organisms also live out on the barrier reef, which protects Palau from the energy of the open ocean. Worldwide, coral reefs cover a mere tenth of a percent of the ocean floor yet provide habitat to a quarter of all fish. They host both the most familiar and the most bizarre offshoots on the tree of animal life. Representatives from thirty-one of the thirty-three or so accepted animal phyla can be found lurking on a coral reef somewhere.

Here's more: 450 million people live near coral reefs. Four hundred million people get more than half of their protein from reef fisheries. Annually, reefs provide somewhere in the vicinity of $375 billion worth of goods and services. Oh, and very serious scientists will tell you that these reefs will be pretty much gone by the second half of the twenty-first century, thanks to climate change. Between thirty and forty percent of the world's corals have already died.

On paper, Nikko Bay is a terrible place for corals, at least in two familiar ways. It's warmer than the open ocean, and it has chemical conditions awfully reminiscent of ocean acidification. Yet the thriving coral colonies underneath us don't appear to be aware of these facts. Does the future feel just a shade less gloomy in Nikko?

Across the bay from us is an Asian tour boat; its passengers are in the water, bobbing merrily in orange lifejackets. Faint shouts and the tinny sounds of radio music carry over the water. When they move on, we head over to their spot. Barkley gets in to search for more temperature sensors, and I look down at the cacophonous diversity of coral shapes and colors.

Where it's waist-deep Barkley plants her fins down to stand on the first spot of bare rock I've seen all day. We're in the shade of the limestone edge, with flows of cooler groundwater percolating through crevasses in the island wall and into the bay, chilling our knees.

Barkley roots around on the bottom, then holds out her hand. In her open palm are four flattened pebbles, their glistening surfaces halfway between orange and garnet. I take one and turn it between my forefinger and my thumb. It's pockmarked but smooth to the touch.

"This is coralline algae. It's one of the most sensitive things on a reef," Barkley says, referring not to the rocks but the laminate encrusting them. "A lot of people think it shouldn't be able to survive at this low pH," she says.

Yet here it is. In Palau's Nikko Bay and a few other acidified Rock Island sites, life appears to be shrugging off a sneak preview of the coral-reef apocalypse. Now Barkley, her boss Cohen, and the rest of the team are trying to answer a few pressing questions. Are the corals *really* okay? And if so, how?

Moreover, what does that mean?

***

"Hundred meters!"

The boat slows, far from shore.

"Fifty!"

Ocean chemist Katie Shamberger, a collaborator with Barkley, looks up from the waterproof GPS device she's holding and points slightly to the right. Gary, the Palauan boat driver, expertly course-corrects.

Then he kicks the boat into reverse and we hang in the calm. "We're good," Shamberger announces.

Like Barkley, Shamberger first came to Palau in 2011. At the time, she was a postdoctoral researcher in Cohen's WHOI lab. Now Shamberger is a professor at Texas A&M, and she's brought her own Ph.D. student to Palau with her.

We've arrived at a location tagged on Google Earth, an innocuous spot in the deep blue lagoon between Palau's islands and the barrier reef that rings the archipelago. Palau's most populous island, Koror, is a few miles behind us to the southeast. Nestled in the back channels of Koror is Nikko Bay, where I swam with Barkley. Diagonally south and to the west of Koror are the other Rock Islands, gumdrops and sinuous crests of green, a maze with karst walls and paths through turquoise shallows.

Ahead of our boat, on the barrier reef crest, there's a sliding glint as a line of about-to-break waves crumbles from right to left, the foam after the crash extinguishing each reflection of the Sun before it alights on spot a little farther down the row. "I love that it's so quiet you can hear the waves breaking," Shamberger says, listening for the soft roar.

Then she drops a cylindrical flask into the water, snaps it shut, and pulls it back up to the boat. Methodically, using a plastic tube, she rinses out a glass bottle three times with seawater from the flask, then fills the bottle to the brim. Her grad student Andrea Kealoha injects a tiny amount of mercuric chloride into the bottle, which will kill any stowaway bacteria that might further alter the water's chemistry.

That's a water sample: the bread and butter of ocean chemistry in general, and of ocean acidification field work in Palau in particular. It's the staple crop, the jump shot, the basic building block of an entire scientific case. Shamberger twists the cap on and holds up the full bottle to catch the sunlight. It looks like a bottle of clear seawater.

The samples need to get taken at intervals to match the range of tides, which leaves plenty of down time. And since each sampling run takes seven or eight hours out on the boat, a red cooler is fully stocked with snacks. We have three bags of beef jerky, a bag of dried and candied mango slices, a few sleeves of Ritz crackers, an orange Gatorade (flavor "Mango Xtremo"), bottled water, chewy granola bars, Triscuits, and string cheese.

I sit with Shamberger, munching, and we fill the time with talk of ocean acidification.

The sample she's just taken is infinitesimal progress, a lone pixel in the slowly enhance-enhance-enhancing image scientists are building of ocean acidification. It will be shipped back to Woods Hole along with hundreds of other indistinguishable bottles of seawater. Then twenty minutes of somebody's life, probably Barkley's, will go into testing its carbon chemistry. That's because ocean acidification is not a problem of acid per se, but of carbon.

It's certainly caused by carbon. There were 350 molecules of carbon dioxide per million molecules in the Earth's atmosphere in the late '80s. That climbed to 370 parts per million at the dawn of the new millennium, then 400 parts per million in 2015. It's still ramping up. Putting global warming aside for a minute, wind and waves are churning that extra atmospheric carbon into the ocean.

And despite what the name implies, ocean acidification is not an issue of reefs dissolving in vats of acid. The ocean is merely moving from a pH of 8.1, about the same as an egg, toward the acid side, to a value in the high 7s. By definition, anything from pH 14 down to neutral pH 7 is basic, making the ocean of the future still less acidic than pH-neutral shampoo.

But that's not to say ocean acidification isn't a problem. The pH scale is logarithmic, like the Richter scale for earthquakes. Even the pH decrease of 0.1 that the oceans have experienced so far is more dramatic than it sounds: the world's oceans are even now about 30 percent more acidic than they were in pre-industrial times, and counting. Marine organisms will rue this change.

Imagine a baby coral dropped into Shamberger's sample, a crusty polyp affixed to the bottom of the glass bottle. Imagine it trying to grow, ever hopeful. Inside its tissue are tiny, cloistered cavities of seawater. To build a skeleton, the baby coral snatches calcium and carbonate ions from the water in these cavities, binds them into calcium carbonate, and lays that material down into sturdy crystals called aragonite. This process is known as calcification.

Calcium is normally plentiful in the water; carbonate less so. Together they're crucial to life in the oceans. Many creatures calcify, including corals, clams, abalone, oysters, scallops, barnacles, conchs, whelks, periwinkles, shrimps, lobsters, sea urchins, sea cucumbers, and tiny coccolithophores, whose dead bodies squish together over the eons, turning into chalk.

Palau's limestone Rock Islands are themselves calcium carbonate. They're the twenty-million-year-old backbones of ancient coral reefs from the Miocene epoch, now lifted out of the ocean and encircled by new reefs that live and grow on the bodies of the dead, as corals are wont to do when carbonate abounds.

Fortunately for the baby coral, there are some carbonate ions in Shamberger's sample, and in seawater in general. Perhaps they eroded into Palau's lagoon from the Rock Islands, or maybe they're from a continent halfway across the world. But having access to *some* carbonate isn't good enough. The coral needs as much carbonate as it can get.

And so the baby coral bends the water chemistry in its favor. It works furiously, powering tiny biological channels that pump protons out of the fluid in its cavities. Loose protons in the water would typically join up with carbonate ions, forming a different (and unhelpful) ion called bicarbonate. But by removing protons from its cavities, the coral encourages the opposite. Bicarbonate ions end up donating their protons to the increasingly proton-less mix, making even more carbonate.

The baby coral's cavities become cement mixers, bite-sized shipyards for laying down the hard scaffolding that holds up the soft animal. There's so much carbonate inside the coral's cavities that the aragonite underneath grows like a frost crystal spreading across cold glass.

But the engineering required to make this work is costly. It's an investment of calories to run those proton pumps. The less carbonate there is at the starting block, the harder this shell-building trick is to do for the baby coral as it operates on an energy budget. And without a strong shell, that coral could grow more slowly, or it could weaken and get knocked down by a wave, or it could get burrowed into. The reef could crumble.

Imagine bubbling carbon dioxide into the sample water around the baby coral, as climate change does to the surface of the ocean. The CO_2 dissolves, joining with seawater to make carbonic acid, a chemical that also adds to the sourness of carbonated soft drinks. This carbonic acid gives up protons to the water, which by definition makes the water more acidic. As a consequence, carbonate ions are converted into bicarbonate.

The coral's proton pumps, manipulating the chemistry inside the cavities, are like AC units trying —and failing— to hit the same set indoor temperature as usual during a heat wave. For calcification to work, the coral needs to spend whatever it takes to get rid of protons—to keep a little bit of enclosed fluid way out of balance with its surroundings. Flooding the outside water with even more protons makes that harder.

Each proxy for ocean acidification—protons, pH, carbonate—is tangled up with the others. Wary that jargon will hang up lay people, researchers often restrict themselves to talking out declining pH. But of course protons in the water have a big impact on the amount of carbonate in the water. And carbonate matters most when it comes to building those aragonite skeletons.

The umbrella term for what's changing, the one scientists use, is the saturation state of the mineral aragonite: the measure of aragonite's building blocks in the water compared to what you'd expect at equilibrium, like the amount of sugar you can cram into Southern sweet tea. When aragonite is oversaturated, there's so much of it that flakes of it emerge from the water, even if no corals help the process along.

Part of the reason that calcification and reefs of some kind have been around for over 500 million years of animal life on this planet is that aragonite is very often oversaturated in ocean water. Calcification is just smart strategy in a bull market, and it's almost always a bull market. The coral reefs of today live in a giant, very oversaturated swath of water around the tropics.

So it isn't the shifting ocean chemistry that worries scientists; not in a vacuum, Shamberger tells me. It's how calcifying organisms and ecosystems already trying—and succeeding—to hustle in the face of that chemistry might see their profit margins eaten away by ocean acidification in the next few decades.

Beyond pH, carbonate, and saturation, it is perhaps most illuminating to talk about tipping points: the whens and wheres at which corals and all the other calcifiers can no longer make ends meet. In Palau, the Cohen researchers are trying to understand how reef animals are coping with the changing chemistry of their environments, and under what circumstances they can be expected to fail.

The day's sampling finished, Shamberger and I head back in the deepening dark, the boat bumping over small waves as blue-white Sirius and the constellation Orion tower over the Palauan islands ahead.

But instead of being lulled to sleep I'm sitting there, thinking. A flurry of studies and experiments on ocean acidification began in 1999, when the scientific community first realized the scope of this looming problem, and continues to this day. On a map of the world, coral reefs live only in areas where the water is oversaturated with 3.3 times the aragonite expected at chemical equilibrium. By about 2050, there won't be *any* areas blessed with water so fertile for calcification. Won't this decimate coral reefs?

The answer, according to tests of corals and other calcifiers in aquarium tanks: unequivocally yes. Only what Shamberger, Barkley, and their boss Cohen found in Palau confuses the picture. The aragonite saturation state in Nikko Bay, where I snorkeled over healthy corals with Barkley, hovers anemically around 2.1—well below where most researchers think the tipping point should be. Something about that place must be special.

***

It makes certain poetic sense that a story about surviving cataclysms in the future starts with insights from a cataclysm in the past. In 1998, a vicious El Niño event devastated reefs across the globe, spurring Palau's investment in a marine research center—and giving the first hint that Palauan corals might be able to resist climate change.

Reef researchers are fond of saying that a hard coral is part animal, part vegetable, and part mineral. What happened in 1998 is a catastrophic breakdown of that partnership.

The animal part is a cnidarian, soft and fleshy, closely related to jellyfish and anemones. Inside its soft tissues it farms the vegetable part: photosynthetic algae. In exchange for a good home, the algae contribute the energy they get from sunlight to help feed their hosts. A well-fed host can turn some of that energy into calcifying new layers of mineral scaffolding. Together, hand in hand, the partners climb ever hopefully toward the Sun.

The El Niño of '98, like Niños in other years, saw a break in the winds that push water across the Pacific. Stagnant warm waters changed weather patterns on a global scale, subjecting tropical reefs worldwide to weeks and weeks of warmer-than-usual water.

The photosynthetic algae inside corals short-circuited in the heat, releasing destructive, highly reactive chemicals called free radicals. Perturbed by the conduct of their tenants, many corals expelled their algae to limit the damage.

Normally, the blue-green shoals between Palau's Rock Islands feature dark patches of coral against the sandy bottom. But when the bleaching hit, these shadows turned white as bone. The corals no longer had their algae; the colorful pigments inside were gone. As a result, giant swaths of these corals starved and died.

And on land, Palau was stricken by drought. The trees that jostle to fill out every nook and cranny of the Rock Islands wilted, replacing Palau's most scenic, unique landscape with the rust tones of an industrial wasteland. Groundwater in the porous and populous limestone island of Koror dried up, forcing residents to get their water from the volcanic island of Babeldaob.

In hindsight, all this climate-related hardship was an epochal event. The need for reef conservation and research in a nation dependent on marine resources could no longer be ignored. Three years after the crisis, PICRC, the Palau International Coral Reef Center, was born. Palau had beat out several other Pacific countries for funding from Japan.

And once this research apparatus was in place, another consequence of the disastrous bleaching came into focus. PICRC surveyors noticed a strange pattern when they started monitoring the nation's reef. Yimnang Golbuu, a Palauan researcher, creases his eyes in a smile of recognition when I ask him about it.

"We could see that some of the sites just are doing better than others, in terms of recovery," Golbuu says, over his desk. Perhaps the first Palauan to get a science Ph.D., Golbuu is somewhat of a local celebrity. We're speaking in his air-conditioned office on the second floor of PICRC, where he is now CEO, the head researcher, and the Cohen lab's key collaborator.

"That kind of gave us a clue that things are different in these different sites," he says. Not all the coral had been hammered. There were still spots that looked more or less intact.

But because monitoring hadn't yet begun at the very onset of the El Niño event in 1998, there wasn't a clear explanation for the healthy patches. Were some corals bouncing back faster? Or had the temperature not gotten as high in those sites, causing less bleaching? Or had the corals themselves resisted the heat?

A smaller bleaching in 2010 helped settle the question in favor of that last, and perhaps most intriguing, possibility. PICRC researchers went out and surveyed eighty coral communities across the archipelago. As before, some sites had bleached more than others. But how a spot fared didn't seem to be explainable by records of temperature alone.

"Those sites that didn't bleach as much got as hot or even hotter than other sites," Golbuu says. They weren't spared by milder weather. They were spared, he suspects, because something about the environment had made the corals tougher. It all sounds very familiar. "And now these are the same sites that Anne is finding," he says. "These are very acidic sites."

Cohen herself came to Palau in April 2011, backed by The Nature Conservancy, or TNC, an environmental organization headquartered in Arlington, Virginia. TNC asked for a map of carbonate chemistry to help study the threat of ocean acidification. Cohen was offered several Pacific locations to visit; she chose Palau because of the research infrastructure that had sprung up in the '98 bleaching's wake.

From the start, Cohen had a hunch that some Rock Island locales might have unusual chemistry. The Rock Islands provide a pinball machine's worth of obstacles for ocean water that trickles through toward the innermost bays. In enclosed places like Nikko Bay, the very same place where corals had resisted the '98 bleaching, the water is trapped for months on end.

In these conditions, Cohen knew that the corals themselves can change the water chemistry. It's like breathing under a thick blanket. Just as respiration exchanges oxygen for carbon dioxide, slowly spoiling the air, calcification draws carbonate out of the water, making the process progressively harder in the absence of an influx of fresh seawater. And the corals are literally breathing, too, which adds more carbon dioxide and makes the situation even worse.

Cohen's initial spring trip gave her a sense of the lay of the land. In the fall, she sent in Shamberger and Barkley to test the water in those enclosed bays. It was true exploration, Barkley recalls. "We basically looked at a map and said, okay. Where can we go that looks like it might be interesting?"

Even after they took the water samples, months passed before they knew how extreme conditions in the bays really were. The eureka moment happened not in Palau, surrounded by breathtaking scenery, but back at WHOI after the samples were analyzed. Barkley remembers Cohen walking into the lab with a big grin and announcing that the saturation state of aragonite in Nikko Bay was in the low 2s, far below what they had expected—and far beneath that oft-cited tipping point of 3.3.

"And to date it was the lowest saturation state that anyone had measured on a reef before, so it was kind of this moment where I was like 'No way!'" Barkley says. Having seen Nikko Bay's vibrant corals in person, it was hard to believe.

"It was *wow*," Cohen recalls. "These reefs are at 2100 AD. These reefs are in the future."

Two conclusions stood out as remarkable. First, big boulder corals in the more acidified bays were growing just as fast as boulder corals out in the ocean. And the diversity of corals seemed even to increase in the most acidified places. The team wrote up these findings in a paper with Shamberger as the lead author.

But the paper, ready by early 2012, wasn't public until almost two years later. Twice they sent it to the high-profile journal *Science*, where it received largely positive comments but was sunk by a few critical reviewers. Then *Nature Geoscience* passed, and the team finally submitted the paper to the American Geophysical Union's

Geophysical Research Letters, where it was published. At issue, suggests Cohen, was not the soundness of the science but the unorthodox conclusion.

"When you're going against the community consensus of what should be happening, those papers are very difficult to publish," Cohen says.

As the publishing process dragged on, the team forged ahead. They continued to investigate what was going on in both these locales and the larger Palauan system. As they did, one thing became increasingly clear. Nikko Bay and the other places that hung tough through 1998, with their acidified water but thriving corals, are somehow exceptional.

But what happened then is sure to happen again, thanks to climate change. And then again after that. Only there probably won't be such a long gap between heat waves next time, and ocean acidification is only growing stronger. Problems are piling up.

***

Darker Mirrors

Like many academic communities, the "coral world," is a cozy place. If you talk to coral researchers—say, to ask about Shamberger's provocative paper on the acidified bays in Palau—the same names keep coming up. Everyone seems roughly aware of everyone else.

It's an ecosystem unto itself. In addition to jetting off to tropical islands for their fieldwork, coral scientists keep up with the published results from their peers. They suffer through similar questions about the big problems facing reefs from reporters; they bump into each other at conferences; and they collaborate on each other's papers with a frequency that rivals featured artists in hip-hop albums. And for those who work to understand even more tightly focused problems, like coral bleaching or ocean acidification, the world gets even smaller.

Inside such a world, debate is healthy. It's encouraged. But it's still stressful for the participants. They don't want to ruffle feathers, but they do want to get the facts right and know the stakes are high outside of just their careers. Every single researcher I spoke to believes that reefs are in grave danger and that ocean acidification is an absolutely crushing problem. Crucially, they all want the science done by their field to be right for its own sake, because it will feed into efforts to save as many reefs as possible. Also crucial: these researchers are competing for the same grants.

This all reads as a disclaimer, and it is. Although the Cohen team's methods in Palau aren't challenged, other researchers contest their conclusions and interpretations. Because when it comes to the acidified oceans of the future, there are darker mirrors out there.

Besides the backwaters of Palau's Rock Islands, there are a handful of other places—in the Mediterranean, the Yucatan, Japan, the Galapagos, and Papua New Guinea—that offer crystal-ball glimpses into how ocean acidification will impact entire ocean ecosystems. In each of these places, as in Palau, geological circumstances have conspired to put the reef communities of today in the chemistry of tomorrow. But unlike Palau, each one of these other places portends disaster.

Katharina Fabricius, an ecologist at the Australian Institute of Marine Science, is leading efforts to study the acidified sites in Papua New Guinea. She advised Yimnang Golbuu on his Ph.D. thesis—further proof that coral world is small. In contrast to the corals tucked away in Palau's Rock Islands, the reefs Fabricius monitors are acidified by underground seeps that bubble up carbon dioxide from the seafloor. Further, unlike Palau, these reefs are pounded on by waves and storms.

After returning from Palau, I called Fabricius to ask how her sites compared to Cohen's. What did she think of the Palauan bays as analogs for the future? Did they make her hopeful about the power of corals to resist acidification?

In coral world, high-tier researchers like Cohen and Fabricius slip into a comfortable shorthand; they become, in each other's respectful appraisal, Anne and Katharina. "The problem I see with Anne's sites—and I've worked in Palau a lot, so I know the sites very well—is that they're very, very sheltered," Fabricius says. "The corals are never exposed to any form of disturbance."

For Fabricius and her team, the seeps of Papua New Guinea hold one end of a measuring stick that stretches from the present to the future. That aspect is roughly analogous to Palau, where the water gets more acidic the farther you go into the labyrinth of the Rock Islands.

In Papua New Guinea, the water right around the vents of carbon dioxide bubbles is the most acidified, the least amenable to calcification. Then the water returns to normal as you get farther away from the seep. Or, if you swim towards the carbon dioxide, you can fast-forward through the next hundred years of climate change in the span of a few minutes. The reef dissolves beneath you.

First to die out are the branching corals, which give a reef its dramatic architecture. Initially some and then all of them go, each species hitting its tipping point and then tumbling over the proverbial cliff with even fewer corals left behind. Algae, adaptable weeds with no need to calcify, fill in the gaps where branching corals would normally grow.

Around pH 7.8 the reef you're swimming over is an eerie monoculture, just massive, lumpy mounds of the hardiest corals. And then the bottom drops out. "Once you get to a pH of 7.7, there's no coral reef any longer," Fabricius says. "That's basically what we predict is the threshold for corals in a high CO_2 world."

Perhaps Papua New Guinea and Palau are best considered together. In concert, they allow scientists to study how whole tropical communities respond to changes in ocean chemistry. It would be impossible to do such a thing in the lab.

But even Fabricius' diplomacy suggests a fundamental skepticism about how much insight the Palauan bays offer into the global problem. "Both sites are really important and informative, but they're telling —" she says, and then she stops for half a beat before concluding, "—they complement each other."

It's not just her first objection, the fact that the Palauan bays aren't exposed to waves like most of the world's reefs are. Though that's a big part of it.

Shamberger had discovered that Palauan boulder corals kept on calcifying just as quickly in sites where acidity increased and carbonate levels dropped, but she may have missed the true problem, Fabricius argues. Near the seeps in Papua New Guinea, adult boulder corals were also tough enough to weather acidification. Their larvae were not so lucky.

If coral larvae can't settle down and thrive on an acidified reef, it might not matter how healthy the full-grown colonies are. Corals don't live in a vacuum; in places less protected than Nikko Bay, storm waves can always swoop in and wreak havoc on a whole stretch of reef. In addition to making adult corals spend more energy on calcification, ocean acidification could be the second half of a one-two punch that keeps baby corals from ever getting up off the mat.

And Fabricius thinks there's a deep similarity between Papua New Guinea and Palau, one that leads her to a more pessimistic reading of Cohen's sites. "Many species are missing at the seeps, and many species are missing at Anne Cohen's sites," Fabricius says.

Chief among the unrepresented in Cohen's bays are the Acropora, a genus of branching coral that grows into shapes like deer antlers or wicker tables. Acropora are the main reef building corals in the Pacific, and together they twist and wind into complex topographies for creatures to live under, in, on top of, and around.

"Organisms like crabs and shrimp and fish and mollusks, they all depend on the reef framework," Fabricuius says. "We tend to focus on corals, but the corals are the ecosystem engineers for these seriously biodiverse reefs. And if the branching corals are missing, probably tens of thousands of species are losing their habitat."

Save the Acropora, save the world—or at least coral reefs in the Pacific. Yet the corals in Palau's acidified bays can claim just a few Acropora among their numbers.

And Fabricius isn't the only researcher to pair a more depressing ocean acidification analog with criticism of Cohen's Palau work. Among Cohen's graduate students in

Palau, a hot topic of conversation was a new paper by Derek Manzello, head of a team studying acidification at the National Oceanic and Atmospheric Administration.

Manzello's study, which appeared in the same journal that published Shamberger's Palau findings, is an account of how reefs in the Galapagos have been decimated by bleaching and acidified waters over the last thirty years. But his discussion of the takeaways from the Galapagos veers into a strident rebuttal of Shamberger's Palau work, which had the Cohen grad students abuzz.

Reefs in the Galapagos archipelago were always small and patchy, Manzello's paper explains. But the El Niños of '82-'83 and '98 raised temperatures by three or four degrees Celsius for several months. Terrible bleaching ensued. Now, besides a few scattered clusters of coral, only one Galapagos reef hangs on, and it's composed solely of those tough boulder corals Fabricius sees close to her CO_2 seeps. The other reefs have disintegrated.

In a preview of the cruel synergies oceanographers expect from future climate change, low carbonate levels likely made recovery impossible. With no carbon dioxide seeps or trapped water to speak of, the Galapagos Islands simulate ocean acidification in yet another way. Water from deep below the archipelago rises to the surface, bringing higher levels of dissolved carbon dioxide. This then lowers the pH and the carbonate available in shallow waters.

Manzello saw that the growth rates of the massive boulder corals, the same ones Shamberger studied, were higher than expected in the more acididc places. So far, no problem with Shamberger and her optimistic finding. But these corals were less dense then they should be. They were growing up reedy, not tough.

"Naturally acidified coral communities in Palau provide an intriguing contrast that, at first, seems to contradict the findings presented here, as well as those from [Papua New Guinea]," he writes. Then the hits come one after the other.

Palau's corals have had an easier ride: in '98, the temperature only spiked by one degree instead of the three or four degrees the Galapagos saw. Again, the Palauan corals are protected from waves. Shamberger didn't report coral density, so the Palauan corals may very well be growing fast at the expense of toughness.

And Shamberger saw that the diversity of corals was high, but was it the *right kind* of diversity? From the picture on the front of her paper, it looks like the acidified bays have mostly "fleshy" corals with weaker structures. Again, where are those reef builders?

Putting these questions and those raised by Fabricius to Barkley, Shamberger, or Cohen yields firm rebuttals. No no no, the Cohen team members say. We have answers to the kind of questions Fabricius and Manzello raise. We just haven't told anyone yet. Beyond Shamberger's paper, the team is quietly assembling a stronger, broader case. As they learn more, they're feeling more confident that their sites are exceptional and informative. But they're holding the new stuff, which will appear in future papers, close to the chest.

It's part of the fundamental herky-jerkiness of scientific progress. The outside world knows only what's been written up in the journals or presented at conferences. Regarding the Palauan bays, outsiders know only Shamberger's paper. That's it. Meanwhile, the process of taking field observations, collating them carefully, wrapping them up into an article that makes everybody happy, and shopping that article around until its accepted by a journal can take years.

The team has measured densities, they say, and the corals in more acidified water don't seem to be less dense. In terms of species composition, they've found that the different acidified bays each seem to have a different combination of coral, suggesting that adapting to low pH is a problem that can be solved multiple ways. And, yes, there are at least some of the branching Acropora. Only one place is dominated by those massive boulder corals, the ones so imperturbable that Fabricius says she's seen them in Hong Kong harbor.

Cohen herself is warm but direct, matter-of-fact to the point of bluntness. In her office at WHOI, I ran through some of the criticism while her dog, Luna, gnawed on a bone in the corner. Cohen says that many of the objections misconstrue what her team is trying to do in Palau.

"We have a low pH environment in which coral communities appear to be thriving," she says. "It doesn't matter that there's other things covarying. The fact that coral communities can thrive, in low pH environments, is a big deal. It's not expected."

"Could it be because temperature is higher, light is lower, flow is lower, it's a low nutrient environment; is that why they're able to do it?" Sure it could, she says. Her team is trying to figure out why. But these communities are indisputably there despite the low pH, and they seem to be thriving.

The seeps that Fabricius studies in Papau New Guinea, Cohen says, vary "wildly," inducing dramatic shifts in chemistry. That makes them no better an analog to the oceans expected in 2100 than Palau. And the small numbers of branching Acropora in the Palauan bays may be due to the fact that these corals prefer well-lit areas with lots of current. Acidification might not play a role at all.

"You've seen Nikko Bay, you've seen the communities," Cohen tells me, in response to the idea that the framework-builders are missing. "There's certainly corals in there that provide the topography. Nikko Bay is not a flat cement pavement."

Cohen, like her critics, wonders why the information coming from Palau so contradicts the expectations of her field. But she presents the incongruity as a real, ongoing research problem the team is delving into.

It could be that the corals in Palauan bays are the best of the best when it comes to resisting ocean acidification, superior to their kin elsewhere in the Pacific. This isn't evolution as it is normally construed, where a population is genetically isolated and changes to better fit its conditions. The coral communities in Nikko Bay are still connected to the open ocean, so they must still occasionally interbreed with outsiders.

Instead, Cohen turns to an explanation offered by Stanford marine biologist Steve Palumbi. In a strikingly similar case to Cohen's, Palumbi studies corals that live in two shallow pools in American Samoa. One pool gets much hotter than another, but the corals in that warmer pool don't bleach. In a bit of research Cohen's team hasn't yet carried out, Palumbi found that the heat-resistant corals have a set of similar genes—evidence of some kind of evolution, despite the fact that the pools are connected to the ocean.

Palumbi's working theory is that only heat-resistant coral larvae can settle in the hot pools to begin with. Cohen thinks the same thing might be true in Palau: maybe the outside larvae that can't handle Nikko Bay's chemistry don't make it through the gauntlet at all. Just getting through the gate is enough of challenge to make sure the corals stay resilient.

Another explanation, the kind favored by Fabricius and seen as an open question by Cohen, is that the environment is helping. Nikko Bay is so protected from storms that Palauans stash their boats there during typhoons. Or perhaps other characteristics of the water or water chemistry are encouraging corals to grow.

After all, Nikko Bay hosts no fewer than three giant clam farms in addition to gorgeous corals. Giant clams, like corals, are calcifying animals that can feed both from sunlight and by filtering little creatures from the water. Maybe they just get so much food that the acidity doesn't matter. Clearly, calcifiers in the bay are finding some way to make ends meet.

And then there's a third possible explanation, a stranger one, with longer odds but even greater implications. "Most of what we expect corals to do in low pH, we get that from our experiments," Cohen says. "Have our experiments really given us the right answer?"

"Maybe the experimental conditions are completely unrealistic," Cohen says, referring to the ominous work done in the confines of laboratory aquarium tanks. "Basically what you're doing is you're taking a coral from its normal environment and sticking it in low pH. And then you measure it, boom," she says, snapping her fingers. Cohen gestures outside, to the tundra of Massachusetts in February visible from her window.

"Like if I took you here and put you outside with no clothes on today," she says.

When I ask Cohen what further progress her team has made on answering the question, she's unwilling to disclose specifics. But she does offer tantalizing hints.

In parallel to her work out on the barrier reef, Shamberger is measuring the calcification of the entire ecosystem in Risong Bay, the second-most acidified Rock Island site. At the same time, Barkley has been trying to understand just how special the Palauan corals are.

"These communities appear to be functioning okay, but are they at their threshold?" Cohen asks. The question matters because the Palauan bays trap normal ocean water that slowly acidifies as animals calcify. But when ocean acidification changes the entire ocean, the water in the Palauan bays will start out acidified and get even more extreme than it currently is.

To illustrate what these corals face, Cohen holds up both hands, one at eye level and one below her ribs.

"They're down *here*, and the open ocean's *here*, and over the course of the century everyone's going to decline. You know, are they just like *kkkkkch* —" and Cohen cuts her hand into her neck, making a choking sound, "—ready to be pushed over the edge by a small additional decline in pH? Or are they really resistant? What happens if we drop the pH further?"

Though reticent, Barkley herself was willing to share the gist of that research over dinner at Taj, Palau's only and surprisingly excellent Indian restaurant.

Barkley took some corals from Nikko Bay and others from the outer reef, and put them in one of three tanks at PICRC with a sliding scale of acidity. The most acidified tank had a pH of 7.7, the tipping point at which their critic Fabricius sees the end of reefs altogether. These corals should have been hard-pressed to grow their skeletons.

But "they didn't care. No one cared. They were fine," Barkley says. Apparently both the Nikko Bay corals and the barrier reef corals just shrugged off whatever chemistry was thrown at them. They kept on calcifying. That makes sense for the Nikko Bay corals, which may have an acquired or innate resistance to acidification, but it's eyebrow-raisingly weird to see in the corals out on the reef, the ones that don't deal with acidified water on a daily basis.

What's important to remember, Barkley tells me, is that her experiments showed a whole range of responses to the adverse conditions. "As a population of corals together, there was no effect. But there's a lot of spread," she says. Individual corals reacted differently, implying a lot of variation within the population. That's a key requirement for evolution.

"But I haven't finished that quite yet," Barkley adds.

***

Seeking Refuge

As of this writing, the scientific scuffles around Cohen's work are not yet settled. "Coral world" is far from a consensus on why the Rock Island reefs look healthy, and whether insights from these communities might apply to the global problem. The debate may wane with the release of more peer-reviewed papers, but that will take time.

But reef conservationists don't have that time. Golbuu, at his desk in Palau's coral reef center, in his tri-part role as researcher, ambassador, and administrator, needs to act now. He's already thinking about how to protect sites like Nikko Bay. "These are naturally strong places," Golbuu tells me. "They would serve as refugia for the other places in Palau."

My ears perk up. It's the first time in Palau I've heard the particular word used, and I've been waiting. Ecologically, refugia are the places species linger after they've died out elsewhere. When outside conditions improve, they radiate back out like pairs of animals disembarking from Noah's Ark.

As Golbuu saw when he started monitoring the recovery of Palau's reefs, it's clear that some places might be less vulnerable to climate change than others. These places, which occur on both small and large scales, are potential refugia. The search for them is the vital thread connecting 1998's epochal bleaching to conservationists, Cohen to Palau. And at the beginning of this thread is Rod Salm.

Salm is the well-spoken, well-traveled director of marine conservation for the Nature Conservancy's Asia Pacific region. His resume is a naturalist's fantasy: Mauritius, Sri Lanka, India, Pakistan, and the Seychelles with the World Wildlife Fund in the 1970s; a doctorate studying the Chagos Archipelago; then a stint in the new world, followed by four years in Indonesia and eight years in Oman.

And then in Nairobi, in 1999, Salm had the inklings of a new idea, triggered by his daughter's need for a high school research project.

Together they drove to the Kenyan coast and chose a long, thin island running north to south. The east side faced the ocean, catching the morning Sun; the west side was sheltered, with mangroves nearby and motes of sediment twinkling in the afternoon's light. This being just after the El Niño, Salm helped his daughter look for bleaching. Corals on the east side? White as bone. On the west side? Normal.

It was puzzling. With a new job at the Nature Conservancy, Salm began travelling to coral reefs across the Pacific to survey the El Niño's aftermath elsewhere: Indonesia, Papua New Guinea, the Solomon Islands. "I began suddenly to see patterns," Salm says, "particularly in Palau."

His moment of epiphany happened at Palau's Cemetery Reef, where the corner of a Rock Island slopes down to the water's surface. Underneath, the slope continues, with green vegetation replaced by foliose corals the color of yellow ochre, like giant sheets of lichen. At least, that's how it looked in January 2015. When Salm first visited after the bleaching, all the corals were dead.

At the time Salm had swum toward the island, over whitewashed corals and rubble, until he was halfway under the notch cut into each Rock Island by grazing mollusks. Under the overhang, his pupils strained to adjust to the shade. "Suddenly I noticed that the corals [behind me], under my fins, were dead and the ones under my mask were alive," he says. "That's when it hit me."

The shade was saving the corals. It was embarrassingly obvious. It explained what he had seen in Kenya with his daughter: the sunnier side of the island had bleached, while the shaded side, with murkier water, had not. Heat plus bright light could cause the photosynthetic algae to release free radicals, causing corals to bleach. During heat waves, shadier places might stand a better chance. So might places where heat waves were buffered by deeper, colder water, an idea first suggested by researcher Peter Glynn in 1996.

The El Niño of '98 had been a wakeup call to the threat posed by climate change, with corals bleaching in over fifty countries. Yet it left managers of marine protected areas with a sense of helplessness. Protecting reefs from humans was one thing. They could limit fishing, restrict where boats could anchor, oppose coastal development. Global warming was different, implacable. But here was hope.

While many coral reef scientists were studying the death and destruction of '98 like photographers documenting war atrocities, Salm's notion was to pour resources into finding and studying the corals that hadn't bleached. Managers would have the best chance to save these reefs.

Salm first presented his simple idea in 2000, at the International Coral Reef Symposium in Bali. It struck a chord. Billy Causey, now director of marine sanctuaries in the U.S. southeast for NOAA, then superintendent of the Florida Keys sanctuary, stood up to say that natural refugia could explain the bleaching pattern he had seen in the Keys. The World Wildlife Fund and the Nature Conservancy put down money for further research, and a new paradigm was born.

"Refugia were the key piece," says Elizabeth Mcleod, a scientist who works with Salm and the Nature Conservancy. "It became embedded in how we do tropical marine conservation."

By 2005 and 2006, scientists grew increasingly concerned about that other, newer threat: ocean acidification. Researchers, seeing corals struggle in aquarium tanks at low pH, could extrapolate out to a tipping point when the world's reefs were dissolving faster than they could calcify. Algae would fill in the gaps. As coral ecologist John Pandolfi wrote about, the world was on a "slippery slope to slime."

Coral bleaching had been a shock when it first struck, a problem nothing in the conservationist toolbox could address. Strategies had to be developed after the fact. This time, with ocean acidification, the plan was to "have a jump on it when it hit," Salm says.

In 2008, Salm convened a meeting of scientists and conservationists in Honolulu. Together, they crafted a strategic response to ocean acidification, which one attendee aptly described as osteoporosis of the reef. Among their recommendations: to search for reefs with lots of biodiversity that might be less vulnerable to ocean acidification.

Thanks to Salm's work, one method for hunting down climate change refugia—seeking out those shadier places—already existed. But that was for bleaching, and acidification has a different profile. Bleaching happens in pulses, brought by waves of high temperature water. Ocean acidification is more often a mounting, inexorable pressure. They obey different oceanographic rules, too. A refuge for one might not work for the other.

Mcleod and Salm met Cohen, an expert in carbonate chemistry. This is when they pushed her toward Palau where Golbuu offered plenty of support, and where a wide range of habitats were thrown together in close proximity. And there they found far more than they'd bargained for.

***

After Barkley and I get out of the water in Nikko, we head to another acidified yet healthy coral community in Palau, in Risong Bay. We pass through the Rock Islands to Risong through hard, angry pellets of rain as the boat bounces jarringly over the waves.

Then the boat slows to traverse a narrow channel. Trees reach out to nearly meet above, their shadows reflected on the water, yellow boulder corals below. The boat emerges into a clearing, the Rock Island walls and trees curving around us. This is *Chiropsalmus* basin, named for a box jellyfish. Cohen's team calls it the Jacuzzi.

Using a GPS device tied onto a buoy, Barkley and technical diver Pat Lohmann put on SCUBA gear and measure the outlines of the coral growing underneath us. I snorkel above, thinking about refugia, wondering whether I'm swimming in one.

When I asked Barkley about Nikko Bay and Risong's Jacuzzi as refugia, she referred me to the Nature Conservancy's Mcleod. Mcleod, in turn, gently resists the poetic notion of refugia in favor of hard data. "I would be uncomfortable if any scientist says that we know that this area is definitively a refuge," she says.

Perhaps it helps to unpack the Platonic ideal of a refuge, where creatures survive and then go forth to repopulate other areas. In Salm's writings on climate change, he breaks down the search for "less vulnerable" spots into a few dimensions. First is avoidance: a particular place that is entirely spared from adverse conditions. Considering that warming and acidification are both global in scale, good luck finding a coral reef that can avoid them.

More serious is resistance: the ability of corals to experience heat waves and not die, or to live in acidified waters and keep growing. Resistance could be innate, the province of hardened, tough corals, as Cohen suspects is the case in Palau's acidified bays. Or it could be environmental, like the shade Rod Salm saw in Kenya, which may have also saved Nikko Bay's corals from bleaching. It's hard to untangle.

And last is resilience, bounceback potential, which Cohen's critic Fabricius alluded to when she talked about how coral larvae couldn't survive on her acidified reefs in Papua New Guinea. Resilience is a reef's ability to grow back fast, and to send its larvae far and wide.

Presently, the idea of reef refugia seems distant, abstract. But the concept is still a target, the animating principle that drives much of this research. Implied is that reefs like Nikko Bay, that show resistance and maybe resilience, could one day be refugia. That's what makes finding and understanding them a priority.

There's a different way to put it, one that acknowledges a fundamental truth: conservation costs money, both to fund the research and to commit to saving a place. Golbuu, at a January 2015 fundraiser for Palau's reef center, in front of guests including the president of Palau, gave an address in Palauan. But certain metaphors, perhaps uncontained in the language, spilled into English. "Investment," I heard. "Bull market." "Return."

Salm has the same word-choice affectations, perhaps because they go over well with the philanthropists on whom conservation organizations depend. On the day I spoke to Salm, he mentioned that he had spent an hour and a half on the phone with a donor. The donor was about to give a talk to students about winners and losers, and intended to draw heavily on Salm's philosophy of refugia.

Think of your investment portfolio. Natural refugia are the blue chip stocks, Salm tells me. You've seen them survive crises before; you invest in them because you know they're winners. Making sure you have different habitats represented is diversifying. After all, you don't know what future climate change will bring. Connectivity, so the larvae can get out, is your liquidity. Good ecosystem management is picking a good stockbroker.

So to follow the language of Golbu and Salm, are Palau's acidified bays a BUY? It's not the sort of question researchers feel comfortable answering, but here's a guess.

In terms of resilience, and looking at what information Cohen has released, it's unknown whether coral larvae can thrive in Nikko Bay and Risong Bay's Jacuzzi. But because these locations are fairly unconnected from the ocean, it would be difficult for larvae to spread out from them. Middle to low scores on resilience and potential to repopulate.

When it comes to resistance, though—both innate and external, both to warming and to acidification—the Palauan corals get high marks. And of course, Cohen's team is still trying to see just how resistant they are.

Meanwhile the ideal of a refuge—the one weapon reef managers have against climate change, save a reduction in carbon emissions—is still on the horizon. Perhaps these bays will pan out as climate change refugia. Perhaps what researchers learn in Palau will help them find refugia elsewhere. Knowing for sure will take time, which again, there isn't much of.

Back in the Jacuzzi, we climb out of the water, then take the boat back to Nikko Bay. There, Barkley takes water samples at the same three spots she sampled in the morning. As we leave, beside two islands in the middle of the bay, we see a boat tugging an inflatable banana straddled by four whooping Asian tourists.

"This is your refugia!?" I say to Barkley, raising my voice over the engine and the wind. She laughs and yells back at me: It's better than some other things they could be doing.

***

On my last night in Palau, Barkley and I meet again for dinner at the Indian restaurant.

"The first time I jumped in Nikko Bay it was just breathtaking," she says. The reef was more colorful, richer, more diverse than any reef she'd ever dived on, and this was *before* the team knew how acidified it was. Learning that these corals were living in extreme conditions made it all the more amazing.

By now, thousands of water samples, careful measurements, and myriad experiments over the seven trips to Palau have left the team confident about the conditions in places like Nikko Bay, and the response of corals to those conditions. In the acidified spots, coral cover is high, diversity is high, and the reefs appear to be healthy. The problem lies in what to make of these facts.

"It's really easy to assume that oh, well, Palau's doing fine. Reefs don't care about ocean acidification," Barkley tells me. That's the kind of thing climate change deniers would love to hear.

The team has been careful to avoid saying anything like it. They haven't even promised that they've found refugia. But Barkley still feels the work on Nikko Bay can be a source of hope. It means that somewhere, corals can survive these hostile conditions.

On this trip to Palau, Barkley has been taking water samples over the entire island system. It's the broad survey the Nature Conservancy originally requested, finally coming into fruition.

She's working with Salm and Mcleod, who want a map of carbonate chemistry across the Palauan islands to feed into their algorithms and compare with satellite data from other places. "We need to understand: what are those patterns?" Mcleod says. "How do we identify those potential refuges across the archipelago without having to jump in the water and sample every coral?" Barkley's map, once produced, will inform searches for refugia around the globe.

Using satellite images, Barkley has already found another place with a similar landscape to the Rock Islands, in Indonesia. Perhaps the pitted limestone islands there harbor acidification-resistant corals, too. But a scouting trip planned for the spring of 2015 was scuttled when obtaining permits proved a challenge.

In the meantime, Barkley's goal is to give Golbuu and Palauan officials a stack of maps that show pH and climate change tolerance. That would indicate the places she thinks have the best chance of surviving ocean acidification over the next century.

But as Golbuu told me in his office, the process of protecting the acidified Rock Island bays has already started, even before Barkley's comprehensive recommendation comes in. Nikko Bay is at particular risk because it is close to Palau's population centers, making it more vulnerable to pollution, development, and sediment runoff.

These corals "might survive the end of this century," Golbuu says, "but before then we'll kill them with all the activities we do on land." Each year, Palau hosts more than 100,000 international tourists, over five times as many visitors as the nation has full-time residents. Even the most remote, pristine dive sites are ringed with tour boats; down below, day after day, a few dozen primates swim with the sharks.

Development to accommodate the tourist industry or simply to modernize, including a new highway that rings the large island of Babeldaob, are threats to the same near-shore reefs that may be resistant to climate change. A few Palauan reefs, which survived the '98 bleaching and might have been promising refugia candidates, have already been wiped out by the sand and dirt washing away from building projects.

Golbuu met with some of Palau's traditional chiefs, who wield what he calls considerable "non-Western" power in parallel to the country's modern political system. The chiefs were very supportive of protecting Nikko Bay, he says, citing a concept called *bul* that provides the ethos for Palauan conservation. A *bul* is a moratorium on certain behaviors and can be used to let a tapped out ecosystem rest.

On the day we spoke, Golbuu was weighing how to respond to the chief of Ngermid, the village bordering Nikko Bay. The chief had requested details on why the place was special, but Golbuu was worried Shamberger's highly technical paper would need some explaining.

For the most part, Golbuu is waiting to hear back from the state legislature. "What I told them is right now Nikko Bay is treated like any other Rock Island in Palau," he says. "But it's not. It's very special. So all we are asking you is: try to treat it differently."

The legislature is dragging its feet, but the efforts to raise awareness have already helped, Golbuu thinks. A legislator checked with him after hearing a proposal to bring some sort of tourist submarine into Nikko Bay. Not here, Golbuu recommended, and the proposal was rejected.

As Barkley and I finish picking at the remnants of our dishes, I put the same question to her that had concerned Golbuu. Just how heartened should we be about Palau's special places? Can they last?

Barkley brings up qualifiers. There's the dump near Nikko Bay, which may not be properly sealed. There's the sewage outflow. There are those tourists, she says, joking about them running the banana boat into the reefs. But if those threats can be contained and these corals protected, she says, "they have probably the best chance of any of Palau's reefs of surviving climate change."

***

Beyond the scientific literature, beyond the international conservation organizations, Palauans care about their reefs. They fish. Palauan women gather sea cucumbers and exchange carved sea turtle shells as IOUs. They benefit from eco-tourism. They grind up coral rocks for building materials, or use them to make chemical lime, which many Palauans add to betel nuts before chewing the blood red mixture to get a mild high.

Golbuu feels intimately connected to the corals he wants to save. During his childhood, the village kids would cut through the mangroves, swim across Nikko Bay, and climb the hill to the Continental Hotel, the first high-class tourist hotel in Palau.

"So we'll go up the dock, run up there, jump in their swimming pool and swim, and then they'll chase us," Golbuu says with a chortle, reminiscing. Then they'd jump off the dock and swim back to the village.

Now Golbuu is an ambassador for Palau to the international scientific and conservation communities. He's full of pride for his country, its natural resources, and its people. Saving the reef is an environmental issue, yes, but he thinks Palauans, considering their traditional ways of life, are sufficiently motivated.

"Sometimes people forget why we're doing this, and they think that this is for some other people. No, it's for us," he says. "This is our island. These are our fish." And corals and fish go hand in hand.

It's a complex sort of stewardship Golbuu advocates, a flexible awareness of how resources are shared and how much can be taken. And yet it seems fundamentally Palauan. On a rainy day, I tag along with Golbuu's employees Uly and Lincoln as they do an ecological survey. At one site, while they're in the water, our Palauan boat driver Ben and I huddle together under a small canopy to stay dry.

Ben was a fisherman for twelve years, but couldn't take it anymore, he tells me. He's cool with catching fish to eat them; with maybe giving a few to the neighbors in hopes of a good turn later. But not so much with selling the flesh. Now most days he drives boats for tourists.

In the last two years of being a fisherman, he felt exhausted. "Every night, I prepare myself for killing," Ben says. "I didn't plant that fish."

He repeats himself.

"I didn't plant that fish. The coral made that."